

Line Narrowing of  $\text{AgGaSe}_2$   
Optical Parametric Oscillator  
by Injection Seeding

George H. Watson  
Assistant Professor  
Department of Physics and Astronomy  
University of Delaware  
Newark, Delaware 19716

Research Associates:  
Norman Barnes  
Keith Murray

The use of high-energy pulsed lasers has become the primary means for remote sensing of trace molecular constituents in the atmosphere. LIDAR (lightwave detection and ranging) is used routinely for spatial profiling of trace concentrations of ozone, for example. In particular, Differential Absorption LIDAR (DIAL) is used to provide greater sensitivity. Molecular selectivity is accomplished by wavelength tuning of the laser to a strong absorption of the desired molecular specie. Many strong absorption lines of interest are in the mid-infrared region (2 to 12  $\mu\text{m}$ ). Further, the spectral linewidths of these molecular absorptions are narrow in the gaseous state. Extension of DIAL to molecules such as greenhouse gases thus requires development of new narrow-linewidth pulsed sources of mid-IR radiation.

The Flight Electronics Division (FED) at NASA Langley Research Center is currently developing solid-state lasers for atmospheric applications. As part of this effort, optical parametric oscillators (OPO) are being investigated as sources of tunable radiation in the 2.5 to 12  $\mu\text{m}$  range where development of conventional lasers is subject to numerous difficulties.<sup>1</sup> Parametric oscillation is a nonlinear optical technique for converting laser output to longer wavelengths. Incident photons, typically from a pulsed pump laser, are converted into two photons of longer wavelength, while satisfying energy conservation. The particular split of energy is determined by momentum conservation; the wavelength of interest is usually selected by angle orientation of the nonlinear material with respect to the direction of propagation of the pump beam.

Recently an OPO based on  $\text{AgGaSe}_2$  has been under consideration by the Environmental Sensors Branch of the FED. This material possesses a strong nonlinear coefficient, optimal birefringence, and excellent transmission in the mid-IR. This OPO, pumped by a 1.73  $\mu\text{m}$  Er:YLF laser, was shown to have low thresholds and high slope efficiencies and was observed to have a spectral

linewidth of  $\sim 20$  nm.<sup>2</sup> Line narrowing of the AgGaSe<sub>2</sub> OPO to the picometer level is desired.

Injection seeding is a technique commonly used to line narrow pulsed laser output. By injecting low intensity light from an external single-frequency laser (typically as low as  $\mu$ W) into a laser resonator, the spectral linewidth of the high energy laser can be reduced to that of the external source. Pulsed injection seeding has recently been demonstrated in a  $\beta$ -barium borate OPO in the visible.<sup>3</sup> Here we report cw injection seeding of a AgGaSe<sub>2</sub> OPO in the mid-IR.

Approximately 200  $\mu$ W of 3.39  $\mu$ m HeNe radiation was injected into the OPO, tuned to that wavelength, described in Ref. 2. The seed beam was mode-matched to the OPO resonator to maximize coupling with the pump laser. The HeNe laser operated predominately in a single longitudinal mode with a spectral linewidth less than 5 pm ( $\sim 0.1$  GHz), measured with a scanning Fabry-Perot interferometer.

The spectral behavior of each OPO output pulse was monitored with a 0.5 m monochromator and a pyroelectric camera. Although the monochromator was capable of 0.2 nm resolution and the camera/software combination provided an effective resolution of 0.4 nm/pixel, thermal bleeding to neighboring pixels limited the overall resolution to  $\sim 1$  nm. The spectral response to the pump and seed beams are shown in Fig. 1, indicating the instrument resolution.

A typical unseeded OPO output was observed to extend over  $\sim 20$  nm, confirming previously observations.<sup>2</sup> On successful seeding, the OPO linewidth was seen to collapse to a value smaller than measurable by this spectroscopic technique.

Work in progress includes more accurate determination of the actual OPO linewidth on seeding by using interferometric techniques. In addition, the effects of seeding on the pulse time evolution interval are being examined. Investigation of line narrowing by other methods, ZnGeP<sub>2</sub> OPO work, and pumping with a 2.1  $\mu$ m Ho:YAG laser are future projects.

1. N. P. Barnes, "Tunable Mid Infrared Sources Using Second Order Non-linearities," *Nonlinear Optics*, in press (1991).

2. N. Barnes and K. Murray, "Er:YLF-Pumped AgGaSe<sub>2</sub> Optical Parametric Oscillator," *OSA Proceedings on Advanced Solid-State Lasers*, H. P. Jenssen and G. Drube, eds. (Optical Society of America, Washington, DC 1991), Vol. 6, pp. 322-328.

3. Y. X. Fan, R. C. Eckardt, R. L. Byer, J. Nolting, and R. Wallenstein, "Visible BaB<sub>2</sub>O<sub>4</sub> Optical Parametric Oscillator Pumper at 355 nm by a Single-Axial-Mode Pulsed Source," *Appl. Phys. Lett.* **53**, 2014 (1988), J. G. Haub, M. J. Johnson, B. J. Orr, and R. Wallenstein, "Continuously Tunable, Injection-Seeded  $\beta$ -Barium Borate Optical Parametric Oscillator: Spectroscopic Applications," *Appl. Phys. Lett.* **58**, 1718 (1991).

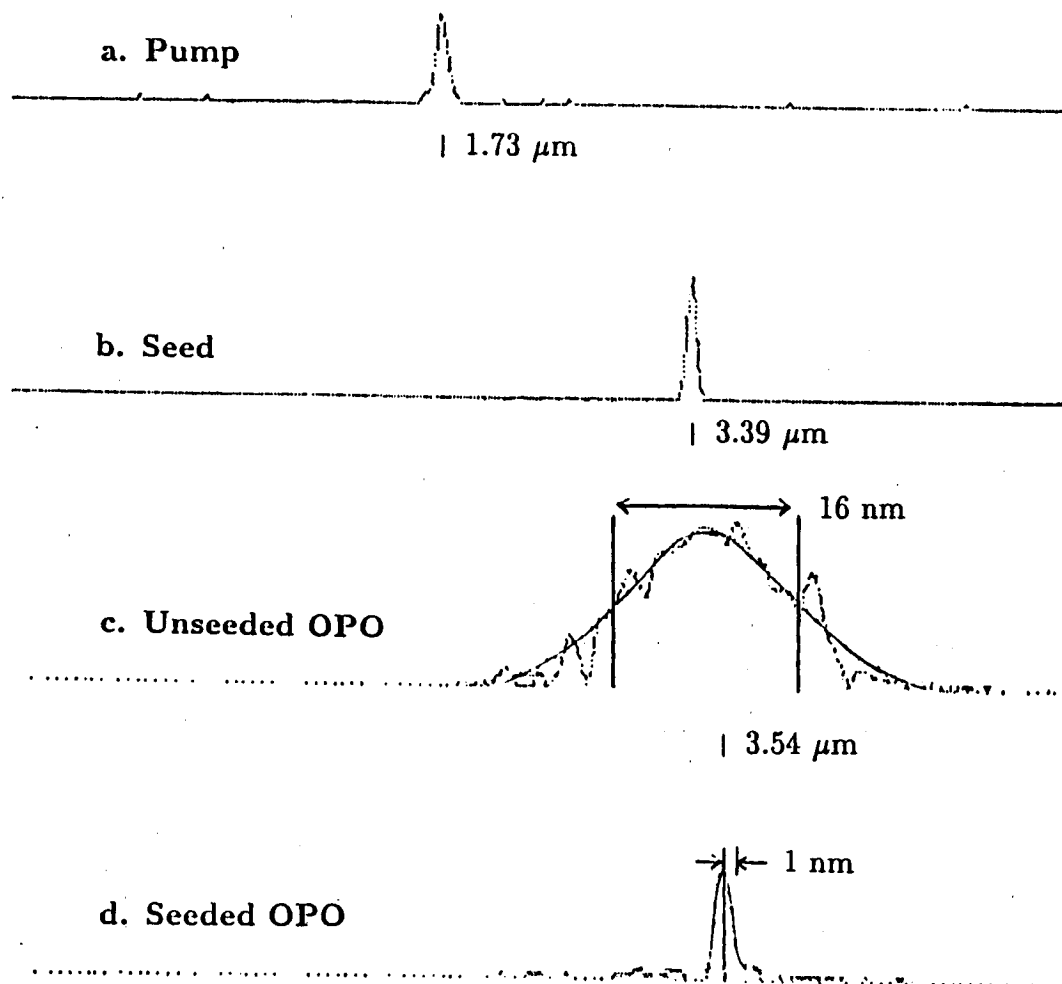


Fig. 1. *Line Narrowing as a Result of Injection Seeding AgGaSe<sub>2</sub> Optical Parametric Oscillator.* Observed linewidths of pump and seed beams are instrument limited. The output linewidth of the seeded OPO becomes narrower than the resolution limit.